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DEPARTMENT OF MINES

THE SOURCE OF ALLUVIAL KIMBERLITE INDICATOR MINERALS IN THE JAMES BAY LOWLAND

by

D. D. BROWN, G. BENNETT, P. T. GEORGE

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Abstract

A source in the vicinity of James Bay was proposed by W.H. Hobbs in 1899 for diamonds found in glacial drift in Wisconsin and Ohio. Recent studies of alluvium in the Moose River drainage basin, James Bay lowland, have revealed the presence of kimberlite indicator minerals, principally pyrope, with lesser magnesian ilmenite and one chrome-diopside, at 20 sampling locations over a 2300 square mile area. The refractive index and unit cell parameters of the pyrope are similar to pyrope from African and Siberian kimberlites. Identification of these alluvial indicator minerals and the presence at Coral Rapids on the Abitibi River of a dike which is mineralogically, texturally, and compositionally similar to kimberlite but apparently lacking pyrope and chrome-diopside suggest that kimberlite intrusions may be present in the area.

The indicator minerals and the kimberlitic dike can be related spatially to deep crustal structures. The Kapuskasing positive gravity anomaly, the axis of which extends northeastward across the area from Chapleau to Moosonee, is indicative of a pronounced upwarp and consequent thinning of the granitic layer of the continental crust. On the eastern margin of the gravity high, the parallel Kapuskasing magnetic high corresponds to horst blocks of magnetic granulite which are bordered and divided by major northeast-striking faults. A regional association of complexes composed of alkalic rocks and carbonatite with the Kapuskasing structure is suggestive of a suitable environment for kimberlite intrusions.

THE SOURCE OF KIMBERLITE INDICATOR MINERALS IN THE JAMES BAY LOWLAND

By

D. D. Brown, G. Bennett, P. T. George[1]

Introduction

In 1966, a 28,000 square mile area from the vicinity of the Precambrian-Paleozoic contact on the southern edge of the James Bay lowland to latitude 49°00'S. and from longitude 79°30'W. to 84°00'W., was mapped by the authors, E. J. Leahy, and assistants as an Ontario Department of Mines helicopter project called Operation Kapuskasing (Bennett et al 1966). During the mapping a kimberlitic dike was identified at Coral Rapids on the Abitibi River which suggests the possible presence of kimberlite intrusions in the James Bay lowland. Previously T. Skimming of Selco Exploration Company Limited (1960) and M. Tremblay of Canadian Hard Metals (Canada) Limited (1963) had found kimberlite indicator minerals, pyrope, magnesian ilmenite and chrome-diopside, in stream sediments in the James Bay lowland in the same area. This report presents a summary of Skimming's and Tremblay's work together with a petrological description of the kimberlitic dike in order to provide a background for future kimberlite exploration.

In the Kirkland Lake area, similar kimberlite indicator minerals were found by H. A. Lee (1965) in the Munro esker and a kimberlite dike was reported by J. Satterly (1948) in Michaud

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township. These occurrences are reviewed. To date, no diamonds have been found in the James Bay lowland, or Kirkland Lake area.

Acknowledgments

The authors are particularly indebted to T. Skimming and the Selco Exploration Co. Ltd., who generously provided the details of their indicator mineral survey and English translations from "The diamond deposits of Yakutia" (Bobrievich et al, 1959). Without T. Skimming's contributions and advice this report would be incomplete. The authors also express their appreciation to W. W. Moorhouse of the University of Toronto who contributed to the petrological study, J. O. Gorman of the Ontario Hydro-Electric Power Commission who contributed drill logs, geological sections, and maps of the Coral Rapids dike, and H. A. Lee of the Geological Survey of Canada who provided an analysis of pyrope. The X-ray and chemical determinations in this report were carried out under the direction of D. A. Moddle, Director, Laboratory Branch, Ontario Department of Mines.

Diamonds in the Great Lakes Region

In the last decades of the nineteenth century seventeen diamonds were discovered in till or in soil derived from till at scattered locations in Wisconsin and Ohio (Hobbs 1899; Blue 1900). The diamonds were found in a 600-mile long and 200-mile wide area, the long axis of which extends from northwest to southeast (Fig. 1). Hobbs postulated that if the diamonds were derived from a common source area, presumably a kimberlite field, this provenance area

should be located at the apex of a fan formed by the diverging, glacial transport paths along which the diamonds are assumed to have been carried by the continental ice sheet. When the assumed paths are extended from the diamond discovery sites parallel to the Wisconsin ice transport directions given by recent, surficial geology maps, the paths converge in the James Bay lowland (Fig. 1) (Hobbs 1899; Flint 1957, p. 127). Schwarcz (1965) however, proposes that the fan converges in southern Hudson Bay, and he proposes that the diamonds were carried from an ancient meteorite crater in southeastern Hudson Bay.

Kimberlite

Kimberlite has been defined by Edwards and Howkins (1966, p. 538) in the following terms:

> "It is an intrusive, undersaturated, feldspar-deficient, igneous rock, usually observed in an altered and brecciated state. It contains essential magnesian ilmenite, and chrome-rich pyralspite garnet with one or some of the following additional accessory minerals, chromiferous diopside, phlogopite, zircon, perovskite, diamond, magnetite, celestite, barite and calcite. The essential olivine of the primary rock is commonly altered to serpentine."

Kimberlite occurs most frequently as pipes and to a lesser extent as dikes. Almost invariably, kimberlites occur in clusters and thus, the conclusive identification of one occurrence may be taken as an indication of the existence of others (Wagner 1914; Edwards and Howkins 1966). In the upper parts of intrusions, kimberlite is commonly moderately soft, greasy, blue-green, blue-grey, green, or yellow-green, altered, hydrated, and decomposed, and is known as blue ground or yellow ground. In Tanzania

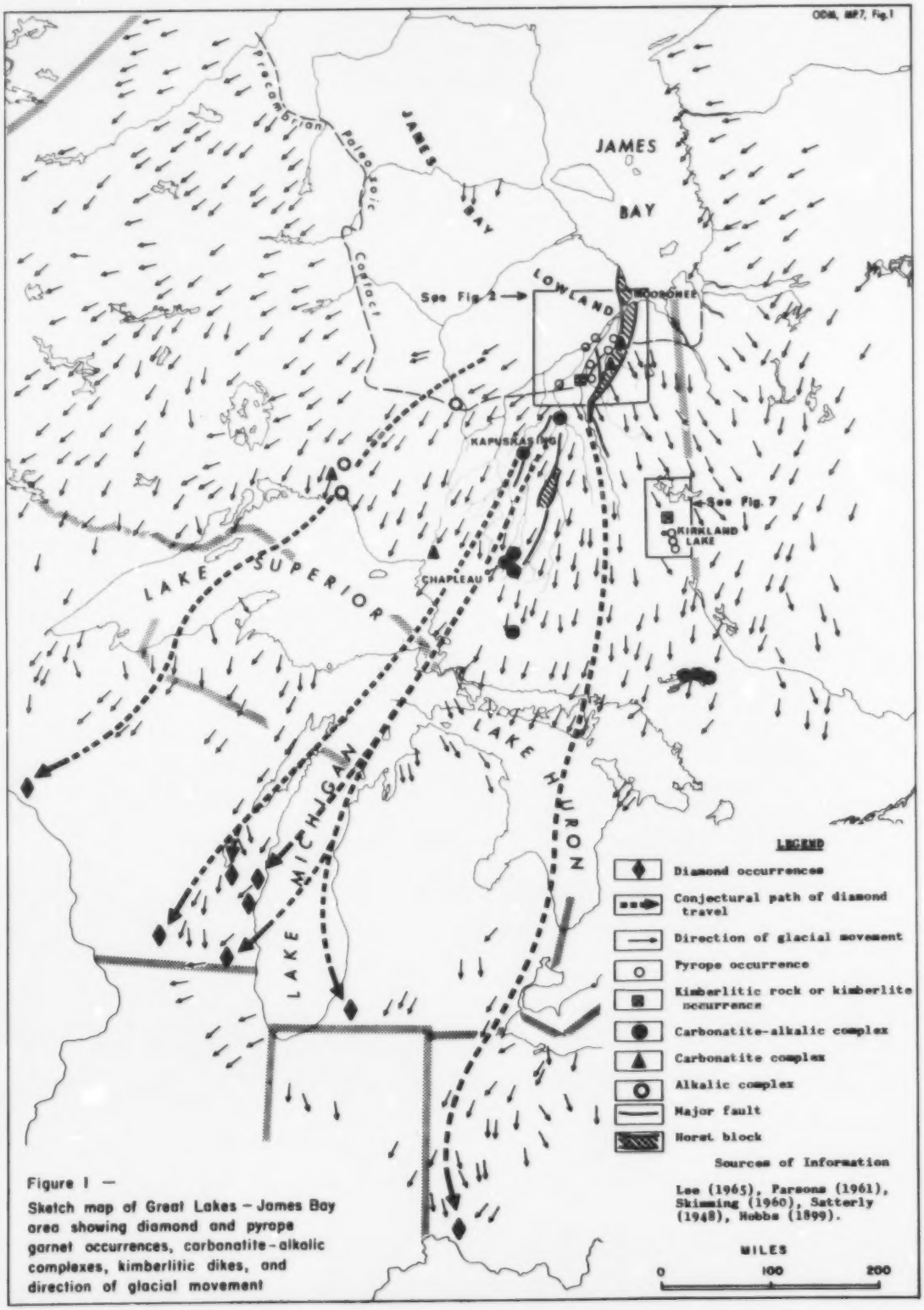


Figure 1 —
Sketch map of Great Lakes – James Bay area showing diamond and pyrope garnet occurrences, carbonatite-alkalic complexes, kimberlitic dikes, and direction of glacial movement

(Tanganyika), a microscopic to megascopic breccia texture which is superimposed on a porphyritic texture (of altered olivine phenocrysts) is the most characteristic feature of kimberlites (Edwards and Howkins 1966). Fragments are rounded to angular and are generally composed of kimberlite and xenoliths derived from the upper mantle, crystalline continental crust or adjacent country rocks; the matrix is composed of comminuted kimberlite. Carbonate veinlets which cut through the kimberlite matrix are common.

Only a small proportion of kimberlite occurrences carry measurable quantities of diamond, and about 2 percent of kimberlites have been profitably exploited (Tremblay 1965). Nevertheless, in South Africa, about 300 pipes have been discovered and 25 have been mined; the bulk of the output comes from only seven which in 1962 accounted for 85 percent of South Africa's production (Toombs 1962; Tremblay 1965). Most diamantiferous kimberlites contain pyrope, chrome-diopside, or magnesian ilmenite but some diamantiferous kimberlites lack these accessory minerals (Bardet 1965).

Kimberlites belong to the group of alkalic basaltoids and are chemically and mineralogically nearest to the melilite basalts (Polutoff 1965, p. 347). Indeed, some authors regard kimberlite as a strongly altered, melilite basalt (Wagner 1914, p. 104; Shand 1950, p. 300). In South Africa and Siberia kimberlite and melilite basalts are spatially and genetically related (Wagner 1914; Polutoff 1965, p. 347). Most kimberlites were intruded during the Mesozoic era and particularly the Cretaceous period.

The James Bay Lowland and Precambrian Shield Area

Physiography

The James Bay lowland is a plain of low relief which slopes a few feet per mile northward, from the Precambrian shield to James Bay (Figs. 1, 2). It has a maximum width of about 200 miles southwest of James Bay and is part of the Hudson Bay lowland. Extensive tracts of muskeg and water-covered, tamarack swamps necessitate the use of helicopters for travel over much of the area during the summer. The Precambrian-Paleozoic contact is marked by a gentle rise of the land surface to the shield area south of the lowland.

Geology

A near horizontal sequence of Ordovician, Silurian, Devonian and Lower Cretaceous strata underlies the lowland and has a total thickness of sedimentation of 1720 feet (Martison 1952) (Fig. 2). These sedimentary rocks are largely covered by Pleistocene drift, marine sediments and Recent alluvium (Table 1).

At Coral Rapids a section of the rocks is furnished by Ontario Hydro diamond-drill core from borings along the Abitibi River (Figs. 3, 4). The core shows that rocks of Devonian age rest directly on the Precambrian basement (Martison 1952). The Sextant Formation comprises the oldest Devonian strata, and consists of a minimum thickness of 91 feet of conglomerate, sandstone, arkose and shale. It is overlain by the Abitibi River Formation which has been divided here into two members consisting

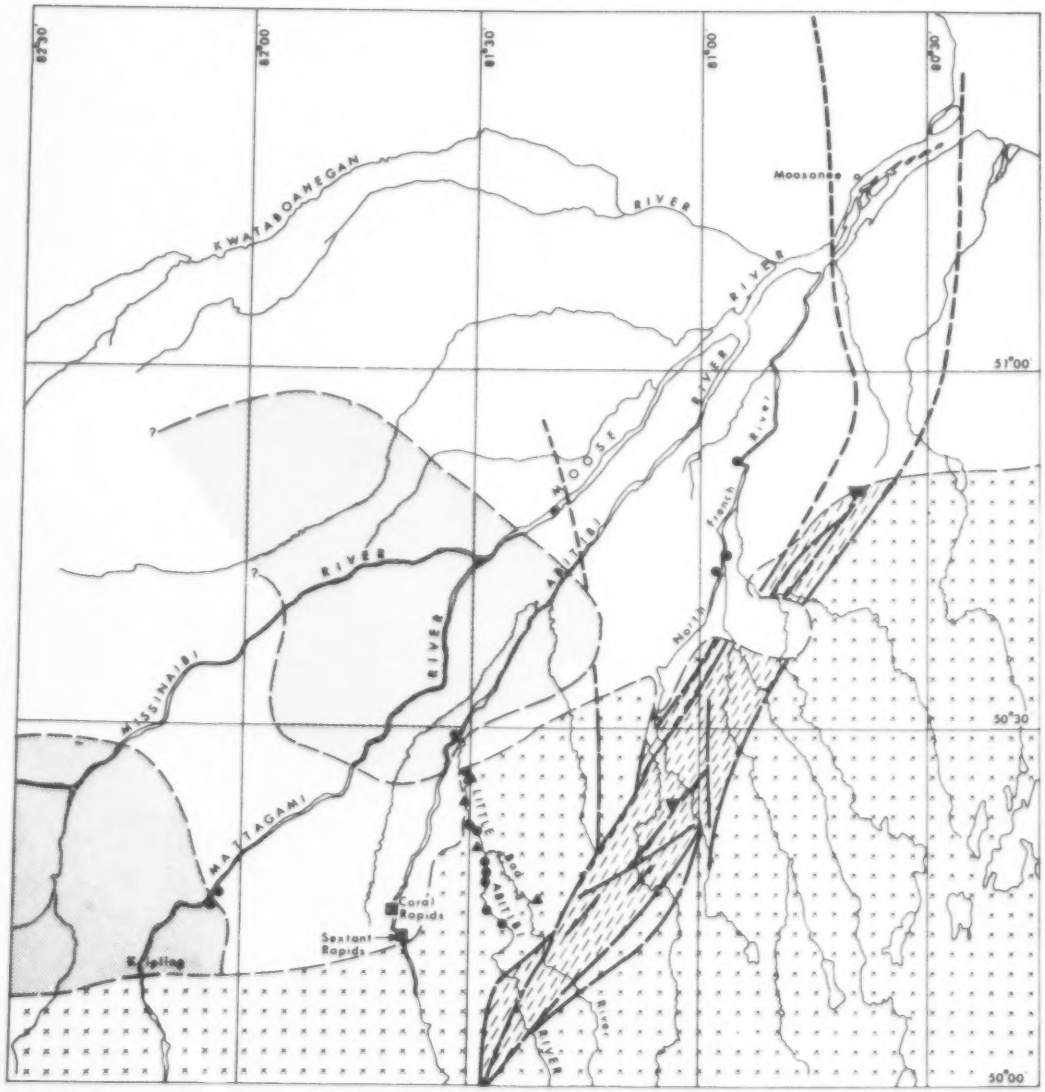


Figure 2 – Kimberlite indicator mineral locations and generalized geology of part of James Bay Lowland Area.

LEGEND

Cretaceous
- Mattagami Formation: kaolin, silica sand, fire clay

Post-Middle Devonian
- Lamprophyre, kimberlitic rock

Lower to Upper Devonian
- Sextant Abitibi River, Williams Island, Long Rapids formations, sedimentary rocks

Precambrian
- Carbonatite complex
- Undifferentiated Precambrian formations
- Kapuskasing magnetic gneissic granulite

SYMBOLS
- Geological boundary.
- Fault.
- Fault projected under Devonian formations.
- Alluvial pyrope.
- Alluvial pyrope and magnesian ilmenite.

Scale of Miles
0 10 20 30

ODM, MP 7, Fig. 2

Table 1 Table of Formations (modified after Martison 1952)

Time Stratigraphic Unit		Formation		Lithology	Maximum thickness (feet)
Recent				Muskeg, peat, sand, gravel	
Pleistocene				Marine clay, Glacial till, clay, peat	35 280
Cretaceous	Lower	Mattagami		Fire clay, sand, lignite	170
Devonian	Upper	Long Rapids		Bituminous shale, shale	285
	Upper and Middle	Williams Island		Limestone, shale, gypsum	416
	Post Middle	Ultramafic Intrusives		Lamprophyre, kimberlitic rock	
	Middle	Abitibi	Upper	Fossiliferous limestone	48
			Middle (Moose River Formation)	Limestone, gypsum shale	254
			Lower	Fossiliferous cherty limestone, sandstone	42
	Lower	Sextant		Conglomerate, sandstone, arkose, shale.	91
Silurian	Upper	Kenogami River		Dolomite, limestone siltstone, shale	296
	Middle	Pagwa River		Fossiliferous limestone	61
	Lower	Severn River		Dolomite, limestone	26
Ordovician	Upper	Undifferentiated		Dolomite, limestone, sandstone	30
Precambrian		Undifferentiated		Undifferentiated	

of a middle member (Moose River), of 40 feet thick, of grey limestone, shale and sandstone; and an upper member, 48 feet thick, of fossiliferous limestone with coral reefs. Ultramafic lamprophyre and kimberlitic rocks observed only at Sextant and Coral Rapids, on the Abitibi River, intrude the Sextant and Abitibi River formations. The intrusions are post-Middle Devonian and may be Mesozoic.

South of the James Bay lowland, the Precambrian rocks are mainly metavolcanic, metasedimentary rocks, gneisses, granitic gneisses, granitic intrusions, diabase, granulite and carbonatite and alkalic intrusive complexes. The carbonatite and alkalic intrusive complexes are Proterozoic (Gittens et al, 1967).

The salient feature in the shield area is the Kapuskasing structure, an association of northeast-trending faults, granulite horsts, and a gravity high. The faults are wide, vertically-dipping, magnetite-rich, mylonite zones, and they define the margins of a number of northeast-trending, contiguous, wedge-shaped fault blocks composed of gneissic magnetite-garnet-hornblende-pyroxene-quartz-feldspar granulite (Gaucher 1965; Skinner 1965) of the granulite facies (Figs. 1, 2). These fault blocks together form a horst which is at least 80 miles long, ranges in width from 2 to 12 miles, and transects the regional, eastward trend of the adjacent formations. A series of magnetic anomalies, referred to here as the Kapuskasing magnetic high, occur over the horst and are caused by the mylonite in the faults, the slightly magnetic granulite, and ubiquitous, narrow zones of magnetite-rich mylonite which fill shears and dilation fractures

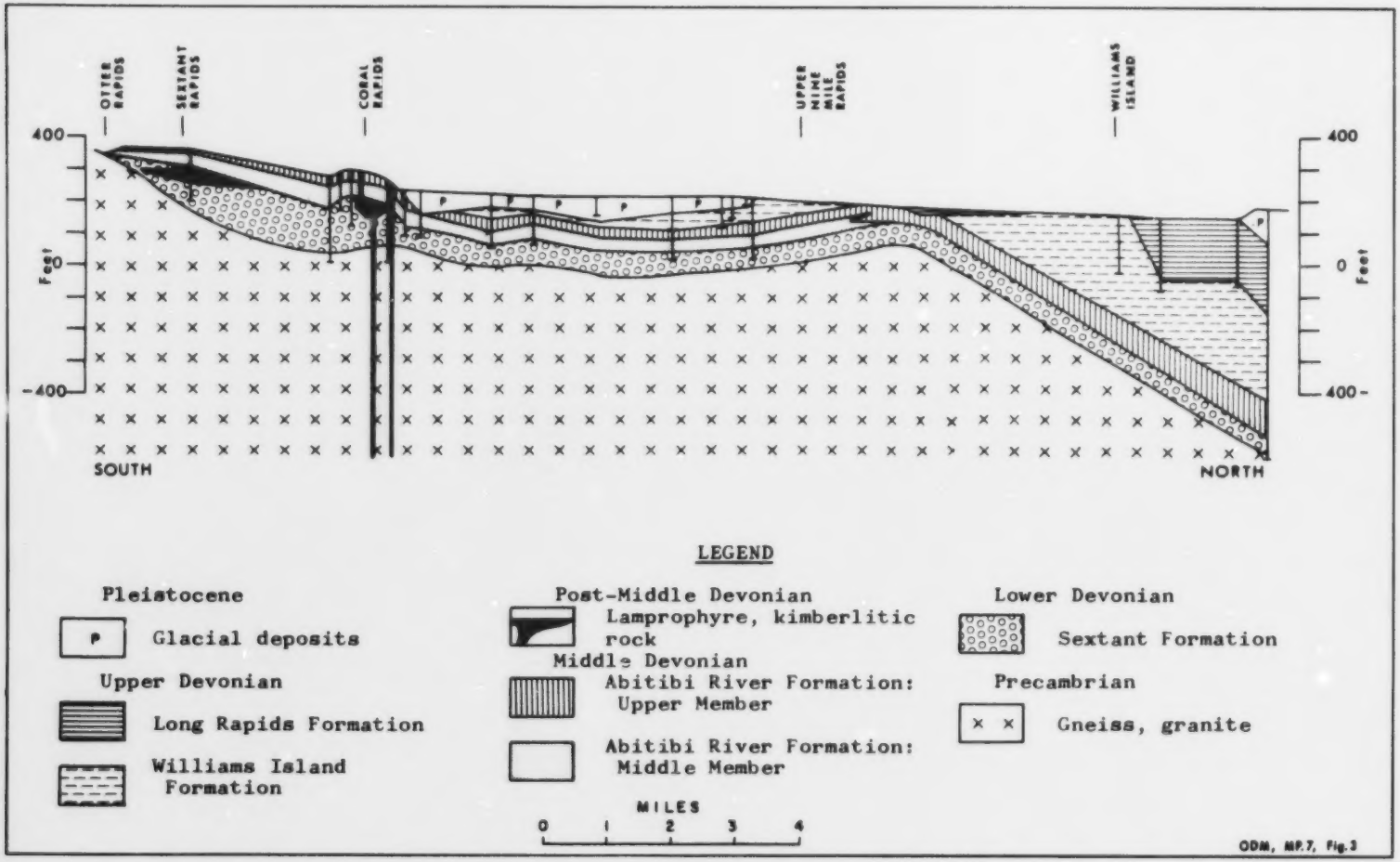


Figure 3 Geological section along the Abitibi River (modified from sections of Ontario Hydro)

in the granulite. The magnetic high extends northeastward to Moosonee near James Bay (Fig. 2) and probably indicates an extension of the horst beneath the Paleozoic sediments. A second magnetic horst at least 60 miles long extends south of Kapuskasing where it is represented by mylonitized granitic rocks, and pyroxene granulite (Bennett et al 1966, p. 43; Bennett in preparation), (Fig. 1).

Approximately 25 miles west of the magnetic high, and trending in a parallel southwesterly direction from Moosonee to Chapleau, Garland (1950) and Innes (1965) have detected the axis of a broad positive gravity anomaly. Garland (1950) thought that the anomaly reflected a thinning of the granitic crust in response to Late Precambrian mountain building forces. Innes (1960, p. 319) "suggests that the gravity pattern marks a major tensional feature of the crust, a fracture zone extending to great depth, which has provided the channel for access to the surface of basic material giving rise to the gravity anomaly". Wilson and Brisbin (1965) state that "the gravity anomaly can be explained by a pronounced upwarp or ridge in the Conrad discontinuity. The granitic crust is thinnest over the orogenic belt and thicker to the east of the belt than to the west." Innes (oral communication, 1967) states that south of Kapuskasing gravity gradients indicate that the source of the gravity anomaly is no deeper than 15 to 20 kilometres (9.4 to 12.5 miles). The absence of normal faults or preserved remnants of low grade metamorphic rocks over the positive gravity field refutes the crustal subsidense interpretation. Moreover, the presence of

granulite horsts east of the gravity axis, high grade metamorphic rocks over the gravity axis, and a large area of low grade metasedimentary rocks west of the western margin of the gravity high (near Kapuskasing), supports the interpretation of crustal uplift along vertically dipping faults and consequent thinning of the granitic crust over the gravity axis.

Proterozoic, carbonatite and alkalic intrusive complexes appear to be spatially related to the Kapuskasing structure. Two carbonatite-pyroxenite bodies, one of which contains a large tonnage of niobium (columbium) pyrochlore-bearing carbonatite have been found by Consolidated Morrison Explorations Limited within the northern granulite horst (Figs. 1, 2). Two intrusive complexes, the Clay-Howells and Cargill bodies, are west of the horst, near the axis of the gravity anomaly. Three intrusive complexes the Hebden (Portage), Nemegosenda Lake, and Lackner Lake bodies are on the southwesterly projection of the Kapuskasing trend (Parsons, 1961).

Post-Middle Devonian Ultramafic Intrusions

Post-Middle Devonian, ultramafic, lamprophyre and kimberlitic sills and dikes intrude the Sextant and Abitibi River Formations at Sextant and Coral Rapids (Dyer 1928; Martison 1952) as shown in Figure 3.

Sextant Rapids on the Abitibi River is formed by a lamprophyre sill, about 60 feet thick, in the Sextant Formation. The sill extends across the river as a sheet, and dips a few feet per mile to the north.

O. E. Le Roy (1902, p. 237A) described the lamprophyre as follows:

"The hand specimens represent a very dark, almost black augite lamprophyre of a type closely allied to the monchiquites. The section consists of aggregates of calcite and serpentine as pseudomorphs after olivine; and pale-brown and pink idiomorphic augites in a groundmass of augites, shreds of biotite, calcite, fluorite, magnetite, and a fibrous zeolite."

The zeolite, which was identified as thomsonite by Walker (1932) forms radial fibrous aggregates one centimetre in diameter.

At the head of Coral Rapids, 2 miles downstream from Sextant Rapids, a lamprophyre sill about 60 feet thick is exposed on the west bank of the Abitibi River and extends along the contact between the Sextant Formation and middle member of the Abitibi River Formation (Fig. 4). Megascopically, the lamprophyre is a grey, fine-grained rock with visible phlogopite. In thin section, it consists of phenocrysts of olivine (Fo_{90} Fa_{10}), radiating fibrous zeolite (thomsonite) in a very fine-grained, felted groundmass of melilite (?), magnetite, and unidentified minerals.

A composite dike composed of lamprophyre and a kimberlitic rock is exposed at the foot of Coral Rapids on the west bank of the Abitibi River and has been intersected by several Ontario Hydro drill holes. The dike is 80 to 100 feet wide, is at least 1400 feet long, strikes N30°E, and has a vertical dip (Fig. 4). The lamprophyre forms the southern half of the dike and is about 100 feet wide. About 20 feet of the eastern edge of the dike at the river's edge consists of kimberlitic rock which appears to intrude the lamprophyre; the contact between the lamprophyre and kimberlitic rock is sharp. The lamprophyre is similar in colour,

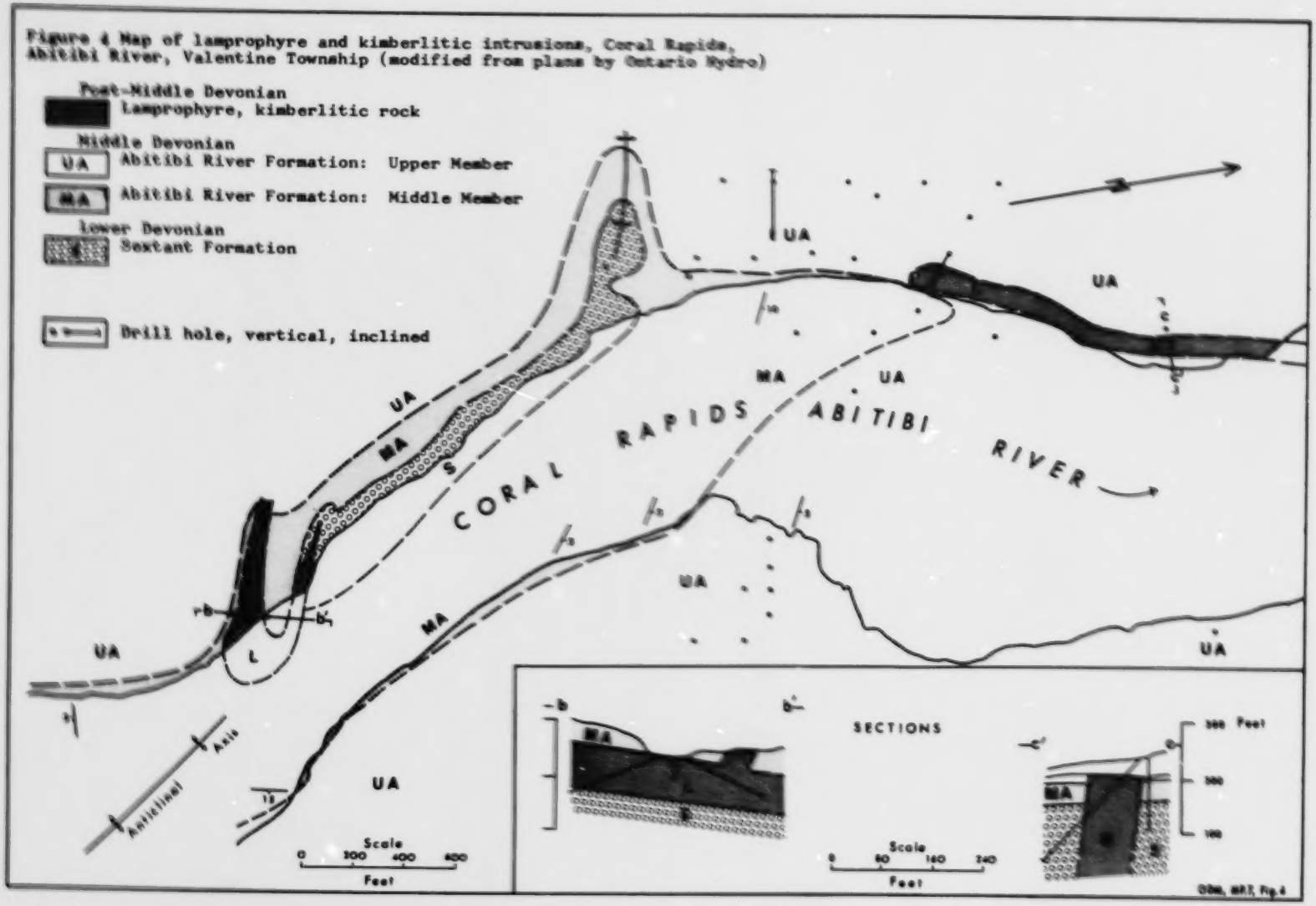


Figure 4 Map of lamprophyre and kimberlitic intrusions, Coral Rapids, Abitibi River, Valentine Township (modified from plans by Ontario Hydro)

but is finer-grained, than the Sextant lamprophyre, and in thin section it contains 25 percent serpentinized olivine phenocrysts and rare, zoned, clinopyroxene phenocrysts in a very fine-grained, felted groundmass of clinopyroxene, saponite (?), chlorite, carbonate, magnetite and other unidentified minerals. The kimberlitic rock which is 80 feet wide forms the northern part of the dike.

Drill sections show that the dike rises from the Precambrian basement and intrudes more than 50 feet of Sextant Formation, 35 feet of the middle member and 20 feet of the upper member of the Abitibi River Formation. No vertical offset was found along the dike.

The kimberlitic rock is pale green, moderately soft, and exhibits a fragmental texture. The fragments form about ten percent of the rock, are rounded dark green microcrystalline basaltic fragments 1 mm. to 2 cm. in diameter, xenoliths of rounded, altered granitic basement rocks 1 to 2 cm. in diameter, and rounded quartz grains, and cleavage fragments of plagioclase, microcline, and colourless kyanite. W. W. Moorhouse (written communication, 1966) describes the fragments as follows:

"The most common fragments are basaltic in texture, are rounded, although some have re-entrant angles. The basalt consists of phenocrysts of olivine, entirely replaced by serpentine, a green-brown mineral with the birefringence of mica, and carbonate. The phenocrysts are enclosed in serpentine, carbonate, and cloudy material enclosing small lath shaped pseudomorphs of plagioclase (or melilite ?) now composed of chlorite or serpentine."

In thin section the matrix is composed of 12 percent serpentinized clinopyroxene, 3 percent phlogopite, and unidentified

zeolite; 10 percent calcite; 8 percent magnetite; 2 percent ilmenite; and 65 percent very fine-grained, clay minerals with an olive-green to yellow birefringence. X-ray diffraction studies show that the clay minerals are mainly montmorillonite, with minor amounts of serpentine and chlorite. The montmorillonite contains calcium as the interlamellar cation and is probably saponite. The ilmenite was identified by x-ray diffraction, and semiquantitative electron microprobe analysis provided by the University of Toronto gave a large amount of magnesium and iron, but only a minor amount of titanium. In places approximately spherical fragments of the matrix 1 to 2 millimetres in diameter are separated by interstitial calcite. Calcite also occurs with serpentine as pseudomorphs after idiomorphic olivine or pyroxene, and some calcite forms thin veinlets up to 5 millimetres wide.

In a study of more than two hundred kimberlite occurrences in Tanzania, Edwards and Howkins (1966) found that kimberlite is not amenable to thin section examination because the matrix is invariably altered and is composed of fine-grained serpentine, carbonate, and chlorite. In the unweathered kimberlite of the Mwadui mine, phenocrysts olivine are altered to olive-green montmorillonite in a carbonate, chlorite and serpentine matrix. All minerals except pyrope, ilmenite, and chrome-diopside are altered. Consequently, recognition of kimberlite in Tanzania is dependent upon the identification of these stable, indicator minerals which form from 0.01 to 1 percent of the kimberlite.

Dawson (1964b, p. 12) in a recent review of the geochemistry of kimberlites stated:

"That although kimberlites contain high amounts of Mg and Fe, they also contain unusually high amounts of K_2O, TiO_2, CaO, CO_2, P_2O_5 and H_2O but their SiO_2 content is often low; these features combined with a high K/Na ratio and a comparatively low Mg/Fe ratio serve to distinguish kimberlites from most peridotites and serpentinites. Chemically the kimberlites are most similar to alnöites, and there is every gradation from kimberlites and alnöites to carbonatites. Moreover, the high concentration of Li, Rb, Sr, Ba, Y, La, Zr and Nb found in kimberlites is most similar to that found in carbonatites and associated igneous rocks."

Daly (1933) and Williams (1932) have compiled many analyses of kimberlites (Table 2) which show a wide range in chemical composition.

Chemical analyses of the Coral Rapids kimberlitic rock and lamprophyre are given in Tables 2 and 3 along with analyses of kimberlites, peridotites, melilite basalts and alnöites from other areas. Compared with other kimberlites the Coral Rapids kimberlitic rock is low in MgO and high in CaO but has a similar Na_2O, K_2O, Sr and Ba. Compared to average analyses of alnöite and melilite basalt, the kimberlitic rock has somewhat similar MgO and CaO but much lower K_2O and Na_2O.

Chemically the Coral Rapids lamprophyre does not resemble the kimberlitic rock with which it is associated. The lamprophyre bears some resemblance to analyses of alnöite and melilite basalts.

The Coral Rapids kimberlitic rock resembles other kimberlites in texture, colour, mineralogy, and softness, and to a certain extent in chemistry. However, because it apparently lacks the accessory pyrope and chrome-diopside essential to the definition of kimberlite, it has been called a kimberlitic rock rather than kimberlite. These accessory minerals, especially pyrope have been found in alluvium of nearby areas.

Table 2 Comparison of Analyses of Coral Rapids Lamprophyre and Kimberlitic Dike to Analyses of Kimberlite, Melilite Basalt, and Alnöite

	1	2	3	4	5	6	7	8	9
	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
SiO_2	36.7	42.54	35.02	27.56-44.08	29.56-46.83	43.54	35.6	35.72	32.31
TiO_2	1.61	1.15	1.22	0.60- 1.48	0- 2.34	0.81	1.37	4.78	1.41
Al_2O_3	7.95	8.52	3.90	3.60- 8.55	0.69- 6.16	3.99	11.6	9.56	9.50
Fe_2O_3	5.67	3.43	5.15	4.15- 7.68	4.18-27.40	2.51	4.88	5.41	5.42
Cr_2O_3	0.08	-	-	-	-	-	tr.	-	-
FeO	5.04	4.20	4.14	3.17- 5.18	2.21- 4.84	9.84	7.15	6.55	6.34
MnO	0.19	-	0.06	0- 0.09	0- 0.01	0.21	0.20	-	0.01
MgO	13.78	20.10	31.29	15.12-34.13	10.80-39.70	34.02	21.2	15.46	17.43
CaO	13.11	4.86	6.80	3.64-15.96	2.42-10.40	3.46	7.75	14.20	13.58
Na_2O	0.30	1.44	0.34	0- 2.72	0.11- 2.55	0.56	0.16	3.35	1.42
K_2O	0.67	0.59	1.05	0- 2.72	0.26- 4.32	0.25	0.19	1.67	2.70
H_2O+	3.95	4.47	7.43	2.82-10.13	4.82-10.19	0.76	5.96	2.67	7.50
H_2O-	4.85	5.18	-	0.64- 5.80	0.25- 7.95	-	1.89	-	-
CO_2	4.08	2.35	2.73	0.19- 2.26	0.20- 7.65	-	0.30	-	-
P_2O_5	nil.	0.32	0.87	0- 1.80	0.41- 2.15	0.05	0.36	0.63	2.38
S	nil.	0.14	-	-	-	-	0.04	-	-
Total	98.0	99.3	100.00			100.00	98.6	100.00	

1. Kimberlitic dike, Coral Rapids, Ontario, analysis by Laboratory Branch, Ontario Dept. Mines.
2. Kimberlite, Star Diamond Properties, Orange Free State, South Africa, analysis by Laboratory Branch, Ontario Dept. Mines.
3. Average of 10 analyses of basaltic kimberlite, S. R. Nockolds (1954, p. 1023).
4. Range of oxides from 25 analyses of kimberlites, A. F. Williams (1932, p. 224-245) analyst J. Parry.
5. Range of oxides in kimberlite, R. A. Daly (1933, p. 552).
6. Average of 12 analyses of peridotite, S. R. Nockolds (1954, p. 1023).
7. Lamprophyre dike, Coral Rapids, Ontario, analysis by Laboratory Branch, Ontario Dept. Mines.
8. Average of 5 analyses of melilite basalt, R. A. Daly (1914, p. 33).
9. Average of 6 analyses of alnöite, R. A. Daly (1914, p. 36).

Table 3.

Trace-Element Analyses of Coral Rapids Lamprophyre and Kimberlitic dike, and Kimberlite and Melilite Basalt (in parts per million)

Reference	V	Ba	Sr	Cr
1. Range of 14 Kimberlites, Basutoland.	65-250	140-2600	120-1100	950-2000
2. Average of 6 melilite basalts, East Africa.		1250	1520	-
3. Coral Rapids kimberlitic dike, Ontario.	600	650	1200	1100
4. Coral Rapids lamprophyre dike, Ontario.	350	600	600	1100
5. Range of 2 kimberlites, Star Mine, Orange Free State.	200-800	1000-1300	600-1100	1200-3000

1. Dawson 1962, p. 552, analysts J. M. Rooke and P. E. Fisher.

2. Holmes and Harwood 1932, p. 405.

3, 4 and 5. Analyses by Laboratory Branch, Ontario Dept. Mines.

Kimberlite Indicator Minerals in the James Bay Lowland

Garnets from kimberlites, peridotites, and eclogite inclusions in kimberlite, ultramafic rocks and basalt contain more than fifty percent pyrope (Wright 1938; Smirnov 1959; Sobolev 1964; Coleman et al 1965). Garnets from all other rocks generally contain less than fifty molecular percent of pyrope. When pyropes are found, therefore in alluvial deposits, they must have been derived from one of the above rock types. However, when pyrope is found in association with chrome-diopside and magnesium-ilmenite, the probability of kimberlite being the source is greatly increased.

T. Skimming (1960) of the Selco Exploration Company discovered that the stream gravels of the Moose River drainage basin area, James Bay lowland, contained pyrope garnets similar to pyrope in African and Siberian kimberlites (Fig. 2). Ninety-four heavy mineral samples were panned, screened, and concentrated at intervals on the Mattagami, Abitibi, Little Abitibi, North French, and Moose Rivers. About 20 garnets were selected from each sample on the basis of colour; violet-red and orange-red varieties were chosed as being indicative of pyralspite garnets which contain a predominant portion of the pyrope ($Mg_3Al_2Si_3O_{12}$) component. The refractive index and unit cell dimensions were determined on these selected samples. These two properties were sufficient to distinquish pyrope rich garnets from other garnets (Fig. 5).

Graphs of the refractive index characteristics of kimberlite derived garnets, containing a predominant amount of the pyrope

component, range between 1.730 and 1.772 with at least one modal peak near 1.745 and possibly a second near 1.765 (Fig. 6). Pyropes derived from Siberian kimberlites range within 1.732 to 1.777 but most have refractive indices ranging from 1.744 to 1.759 (Smirnov 1959). On this basis, 13 garnet grains representing 12 sample locations in the James Bay lowland fell within the range 1.72 to 1.76, with most from 1.74 to 1.76 (Skimming 1960).

Unit cell dimensions of pyrope from kimberlites given by Bobrievich et al (1957) range between 11.496A° and 11.572A°. The unit cell dimensions of the James Bay lowland garnets fell within this range at 11.539A° to 11.555A°.

A plot of the James Bay lowland garnets on Winchell's (1951) determinative chart for garnet gives a pyrope content between 50 and 80 percent (Fig. 5).

In 1962 the Canadian Rock Company obtained an exploration licence of occupation to search for diamonds over a 125 square mile area which extended from the mouth of the Little Abitibi River at its confluence with the Abitibi River to the Precambrian-Paleozoic contact 21 miles to the south. The Canadian Rock Company is an associate company of Hard Metals (Canada) Limited; both companies are subsidiaries of the Anglo American Corporation of South Africa Limited and DeBeers Diamonds. M. Tremblay of Hard Metals (Canada) Limited collected 25 stream gravel samples, each one cubic foot in volume, from locations distributed as follows: 16 from the Little Abitibi River, 6 from the Bad River, and 3 from the Abitibi River. Analyses of the screened and concentrated fractions, by the Central Metallurgical Laboratory, Johannesburg, South Africa, revealed that

eight samples contained mauve pyrope and three contained magnesian ilmenite. One angular grain of chrome-diopside was found at the confluence of the Little Abitibi and Abitibi Rivers. These minerals were believed to have been derived from kimberlite (Tremblay 1963). Except at one location, all the mineral grains were abraided and rounded, and all samples contained very few pyrope grains. Ten larger samples ranging in volume from 1 to 2 cubic yards were also collected and were examined for diamonds; no diamonds were found.

In 1963, six heavy mineral concentrate samples were taken by H. B. Naylor from the Cretaceous Mattagami Formation clay and silica-sand deposit on the Northern Ontario-China Clay property east of the Mattagami River in Kipling township near the Precambrian boundary. X-ray, optical and chemical analyses carried out by R. J. Holmes, Columbia University established the presence of pyrope-almandine garnet, diopside, and ilmenite. The mineral concentrates were too small to establish the pyrope content of the garnet, the chromium content of the diopside, and the magnesium content of the ilmenite. There is qualitative evidence for the presence of chromium in the diopside, but it is not conclusive (R. J. Holmes written communication, 1964).

It was thought that the James Bay lowland pyrope garnets may have been derived from the granulite horst block. The refractive indices and unit cell dimensions of four garnets from the granulite are distinctively different from those of the detrital garnets (Fig. 5).

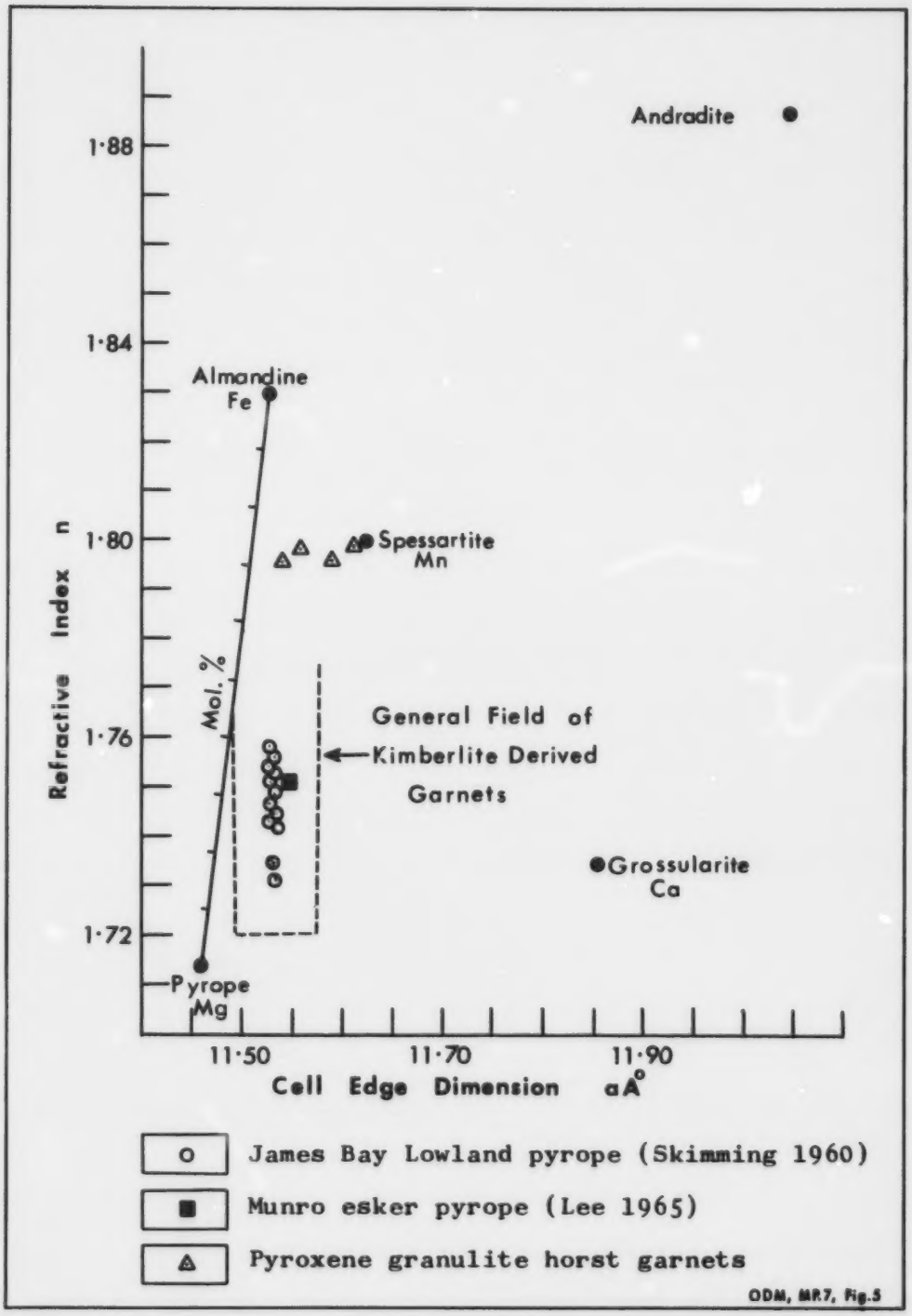
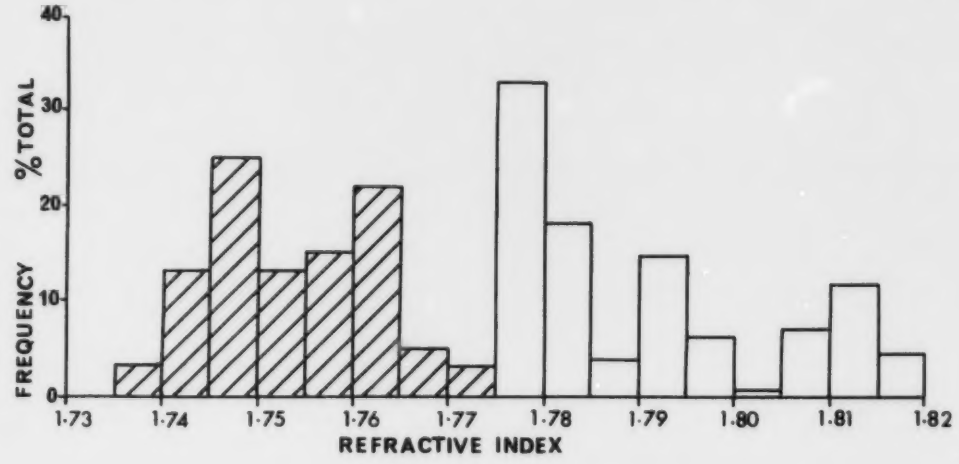
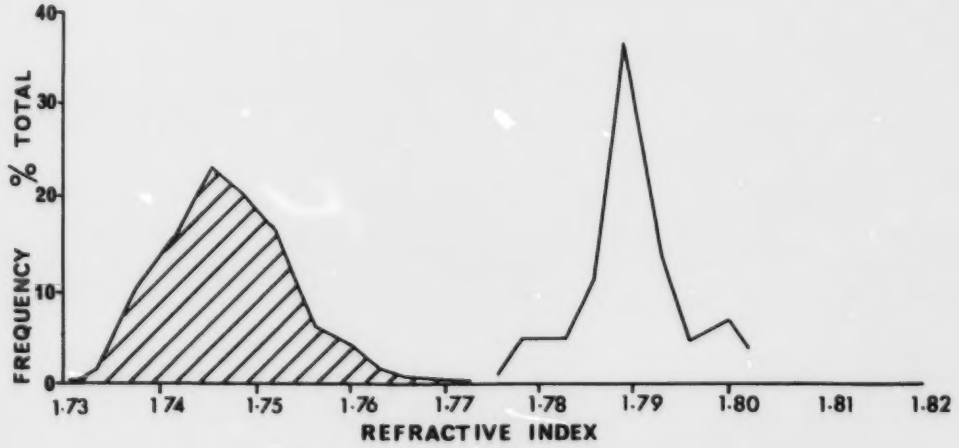


Figure 5 Composition of garnets in James Bay Lowland and Kirkland Lake areas (after Winchell 1948)



Histogram of 1790 pyrope garnets from kimberlite sources.

Histogram of 857 garnets from non-kimberlite sources from Edwards and Howkins (1966).



Cumulative curve of 1400 pyrope garnets from kimberlite sources,

Cumulative curve of 43 garnets from non-kimberlite sources,

from T. Skimming (1960).

ODM, MP.7, Fig.6

Figure 6 Refractive index range of pyrope garnets from kimberlite sources.

Kimberlite Exploration

In discussing the relationship of kimberlite and carbonatite, Dawson (1964b, p. 12) states:

"A survey of the world occurrences of kimberlite has shown that they are closely associated both in space and time with carbonatites or with rock-types that are often found within carbonatite complexes, e.g., alnoite, olivine melilitite, nephelinite and monchiquite. Good examples of this relationship are found in Africa, North America, Russia and Sweden."

Regarding as association of kimberlites with major horst-areas or strongly upwarped areas Dawson (1964a, p. 1385) states:

"Prospecting (for kimberlite) should be carried out in upwarped or horst block areas and preferably along tectonic zones already delineated by the more easily recognizable alkaline and carbonatite complexes. The Precambrian terrane of Ontario between Lake Superior and James Bay, centred on the Kapuskasing area, appears to be in accordance with the above features. It is possible that kimberlites [undiscovered] in this area are the source of diamonds found in the glacial deposits of Wisconsin and Michigan."

In the Kapuskasing structure alkalic and carbonatite intrusions appear to be closely related to north to northeast-trending and vertically dipping faults. Some of the intrusions occur beside major faults within the horst blocks and one lies on a fault west of the horsts near the axis of the gravity high. Present data indicates that ultramafic and kimberlitic intrusions and the kimberlite indicator minerals occur on or near the axis of the gravity high and not within the horst blocks. Accordingly, the most favourable exploration areas should lie west of the horsts and near the gravity axis, particularly in the James Bay lowland.

Kimberlite and Pyrope Garnets in the Kirkland Lake Area

During a study of glaciofluvial transport of rocks and minerals Lee (1965) found over 300 purple garnets in screened and concentrated samples at nine points along the Munro esker, east of Kirkland Lake. From unit cell, index of refraction, and spectrographic analyses, the garnet was identified as pyrope. In one representative analysis, the pyrope is chromium-rich with an index of refraction of 1.75 and unit cell edge dimension of 11.548° (Figs. 5, 7) (Lee, written communication 1967). Lee (1965) found that pyrope was concentrated at eight sites within the esker, and from a comparison with the transport distance of other components, he suggested that the source of the pyrope is probably within a 10-mile radius of the northernmost concentration (southwest Gauthier township). Lee has also established the presence of a chrome-bearing clinopyroxene associated with the pyrope. The mineral has a similar bright green colour as specimens of chrome-diopside from African kimberlite (Lee, written communication, 1967). No source has been reported for the pyrope within this radius, but the source rock may be similar to a six-inch wide kimberlite dike reported by Satterly (1948) in Michaud township, 26 miles north of the northernmost sample point of pyrope concentration and a few miles west of the Munro esker (Fig. 7). Satterly (1948, p. 13) describes the kimberlite as follows:

"A very striking ultrabasic rock was found in hole No. 26 of Marchaud Mines Limited, north of Ludgate lake in lot 8, concession III. The rock in porphyritic with grains of olivine (one-fifth of an inch), rounded books of phlogopite (one-tenth of an inch), and pyrope-rich garnet (one-tenth of an inch). A few foreign rock

fragments, apparently greywacke or quartzite,are present. The cement between the large mineral grains and rock fragments is a crushed aggregate of olivine, in part serpentinized, phlogopite, and a black dust-like mineral (magnetite?). The rock may be termed a kimberlite."

Soviet Prospecting Methods Used to Detect Kimberlite Pipes

Prospecting methods employed by the Soviet Amakinsk expedition, in the western part of Yakutia (eastern Siberia) are described here because the methods successfully located diamantiferous kimberlite pipes. Exploration is based on the testing of the soils and alluvium for kimberlite indicator minerals, pyrope, magnesian ilmenite and chrome-diopside, and diamond which occur in accessory proportions in kimberlite pipes and are frequently concentrated in the residual soils near the pipe (Bobrievich et al 1959). Variation in the resistance of the indicator minerals gives rise to a dispersal pattern which can be used to locate the source. Chrome-diopside is generally destroyed within 30 miles of the source. The limit of pyrope is within 90 to 125 miles from the source (Bobrievich et al 1957). Magnesium ilmenite and diamond are very resistant and consequently can be found much farther from the source that either pyrope or chrome-diopside.

Where indicator minerals were found, systematic sampling was carried out to search for a higher concentration of indicator minerals and the less resistant minerals.

Magnetic surveys carried out in conjunction with alluvial sampling have been successfully used for the detection of kimberlite pipes (Bobrievich et al 1957; Varlamov et al 1962). The positive

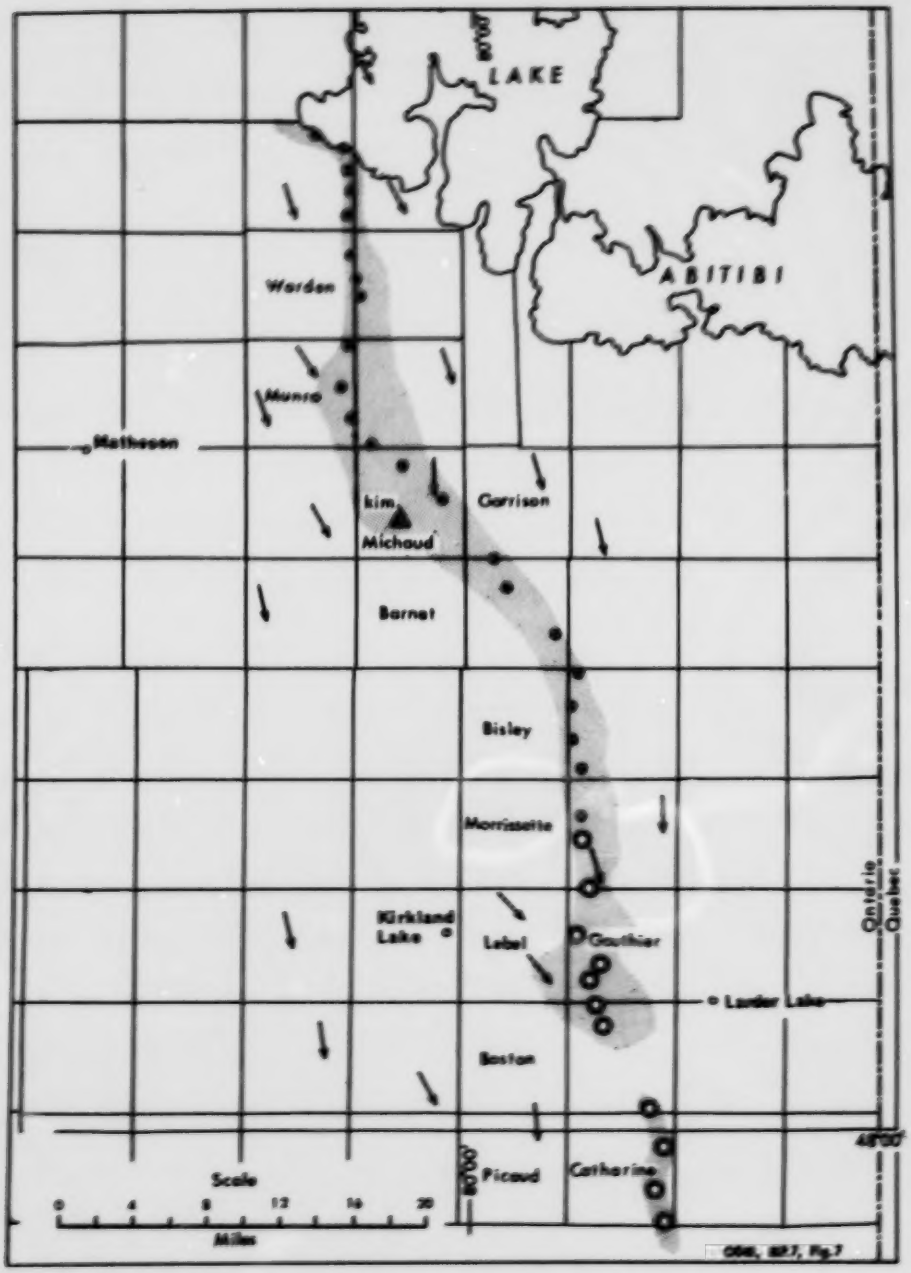


Figure 7 Pyrope garnet and kimberlite occurrences along the Munro esker in the Kirkland Lake area (modified from Lee 1965).

Munro esker and outwash deposits.

Direction of glacial movement.

Sample points.

Pyrope occurrences (Lee 1965).

Michaud kimberlite (Satterly 1948).

Glacial data from Boissoneau (1965)

magnetic anomalies over the pipes in contrast to the weak magnetic background of the near-horizontal Cambrian and Ordovician carbonate country rocks made geophysical identification possible. Similar detailed magnetic surveys could be employed in the James Bay lowland over the Paleozoic and Cretaceous sedimentary rocks.

Conclusions

Although Wisconsin ice movement directions converge from scattered diamond discovery sites south of the Great Lakes to the James Bay lowland, it is not known whether this apex area of Hobb's converging fan is the provenance area of the Great Lakes diamonds. The age and petrological and chemical characteristics of the kimberlitic dike at Coral Rapids, and the geological characteristics of the Kapuskasing structure suggest that the area west of the magnetic high and particularly the James Bay lowland are favourable for kimberlite exploration. The kimberlite indicator minerals are similar to those derived from kimberlites in the U.S.S.R. and South Africa; but the source of the pyrope may be garnet-bearing ultramafic rocks or eclogite-bearing basalt. As in Yakutia, the source is expected to lie no more than 125 miles from the indicator sample locations. The terrane and glacial dispersion and dilution of the indicator minerals in a thick extensive cover of glacial till presents exploration problems.

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Maps

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375 Onakawana Sheet.
376 Partridge River Sheet.
396 Little Long Rapids Sheet.
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